

High-radiance LDP source:

**clean, stable and reliable EUV source for
mask inspection**

The logo for Ushio, consisting of the word "USHIO" in a bold, white, sans-serif font, set against a solid teal background.

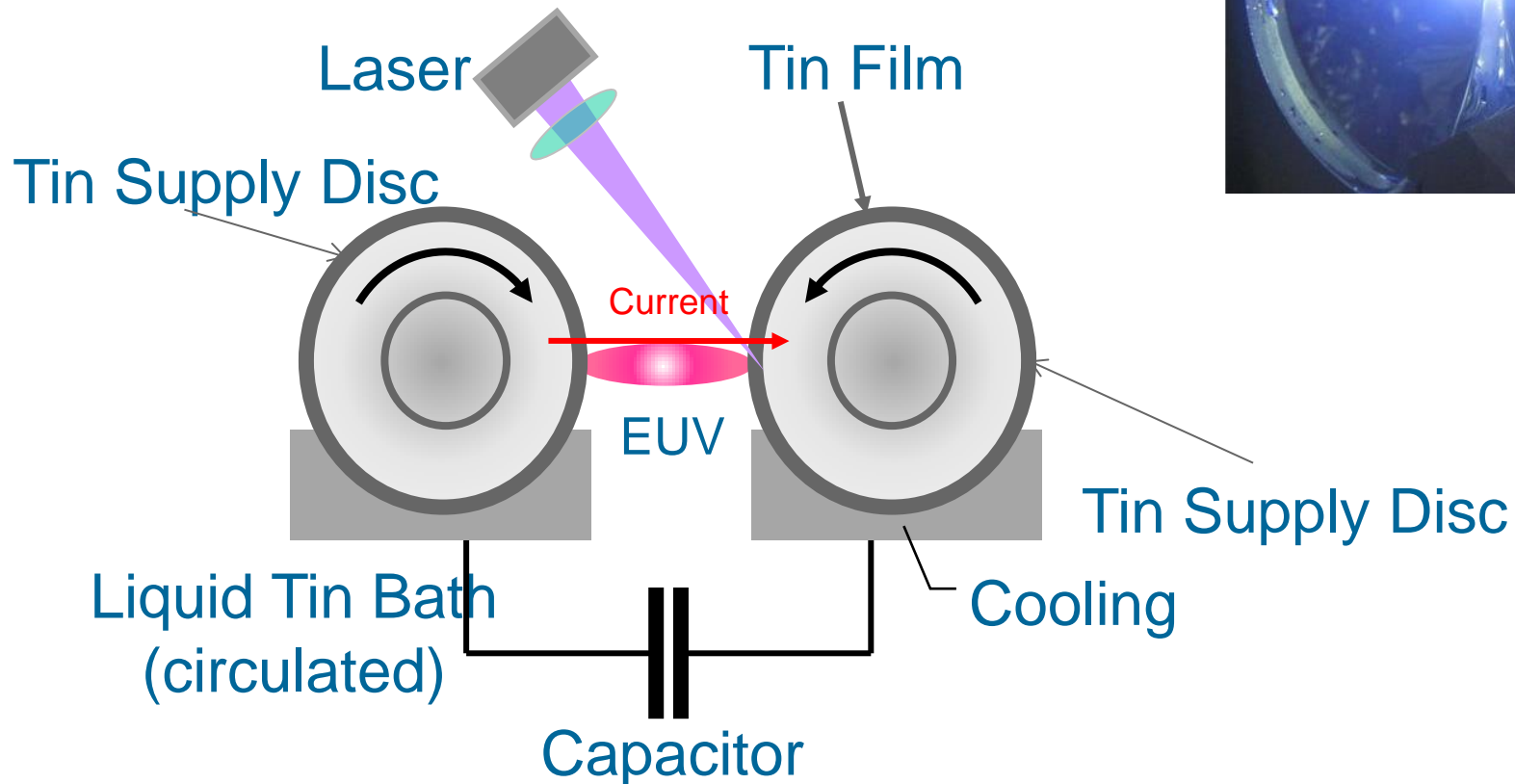
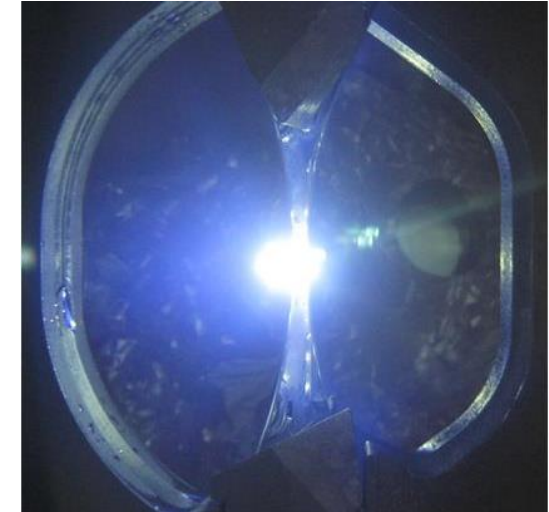
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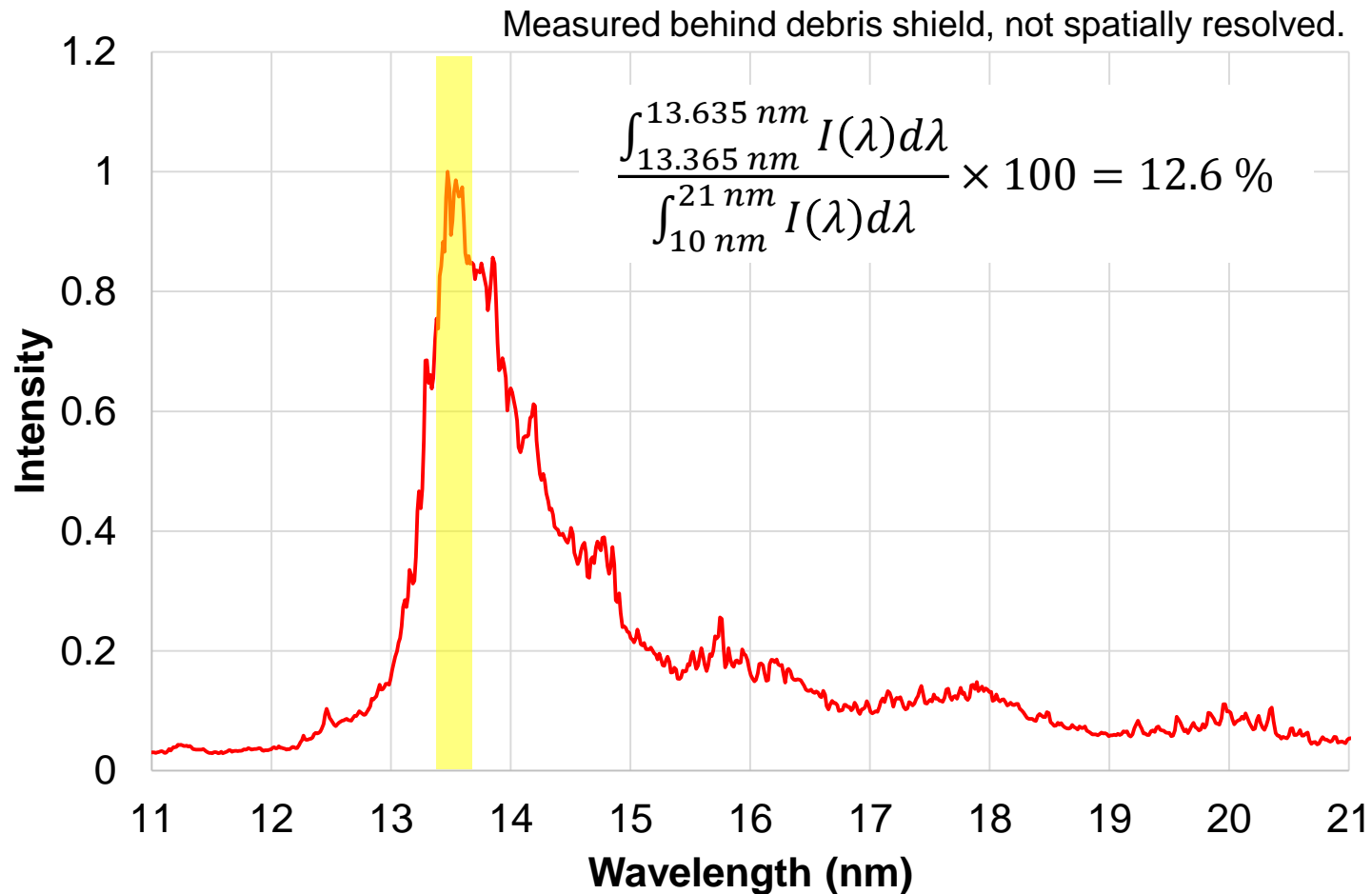
O U T L I N E

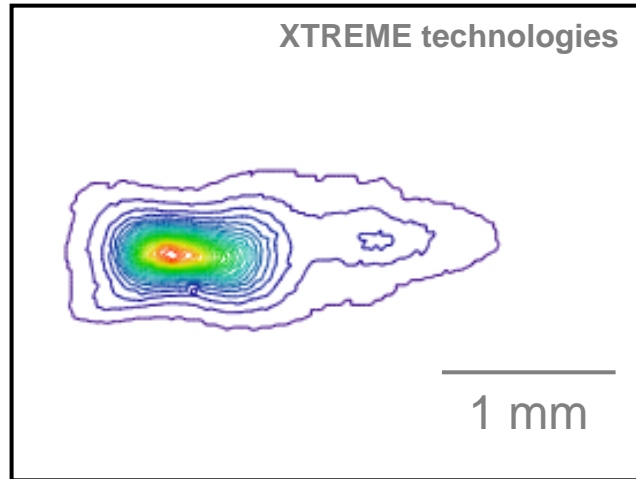
- **Basic principle and characteristics**
- **Key performances**
- **Cleanliness**
- **Stability and reliability**
- **Summary**

- High brightness
- Appropriate plasma size (broad profile)
- Stable: no spatial and timing synchronization needed
- Reliable: 24/7 operation
- Clean: powerful debris shield



- ❑ Similar spectrum to Sn-LPP
- ❑ Beneficial in inspection and other applications



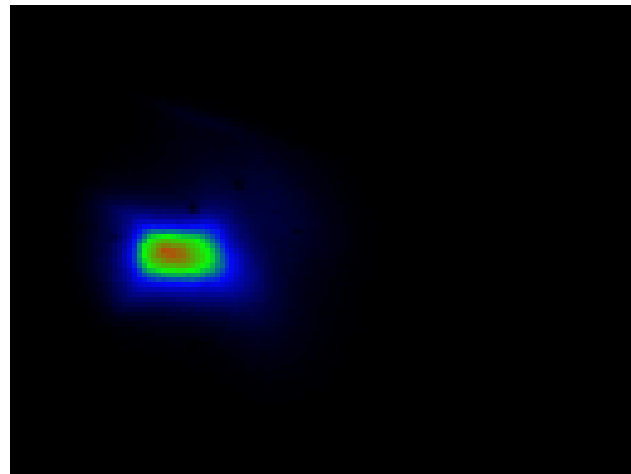


Plasma for lithography beta source

L: $\sim 500 \mu\text{m}$

D: $\sim 230 \mu\text{m}$

High pulse energy



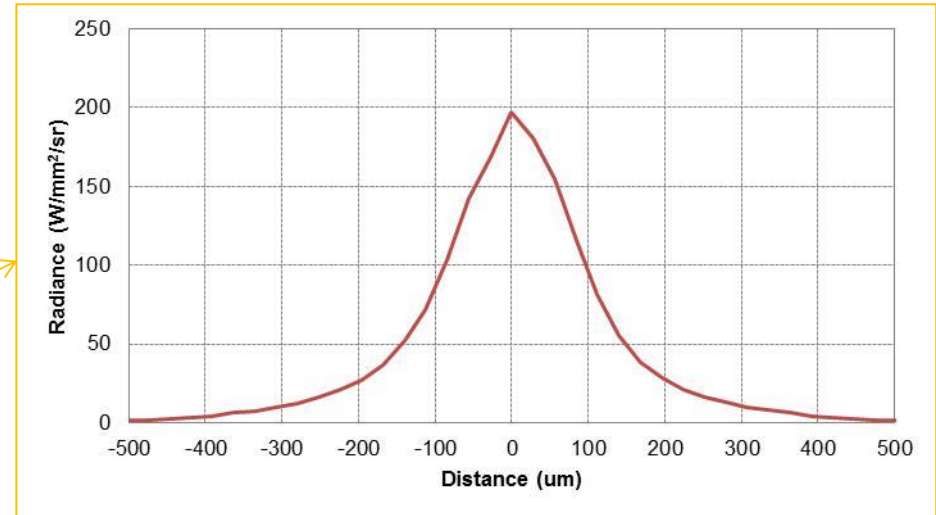
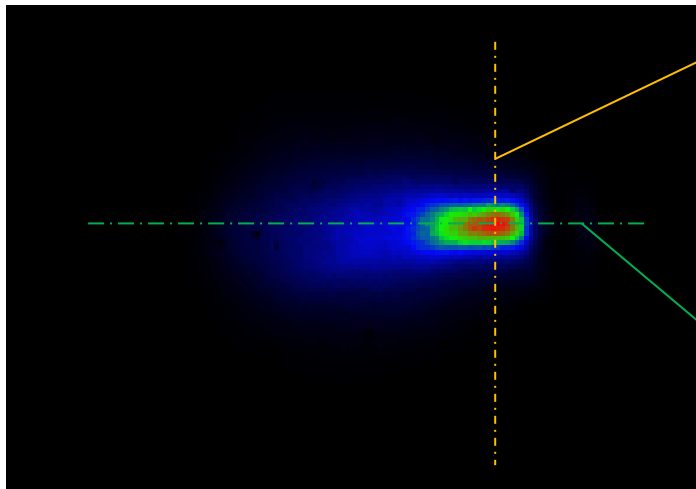
Plasma for mask inspection source

L: $\sim 450 \mu\text{m}$

D: $\sim 200 \mu\text{m}$

Low~medium pulse energy

- ❑ Very high peak radiance at plasma
- ❑ Plasma size smaller than DPP, larger than LPP: good spatial stability

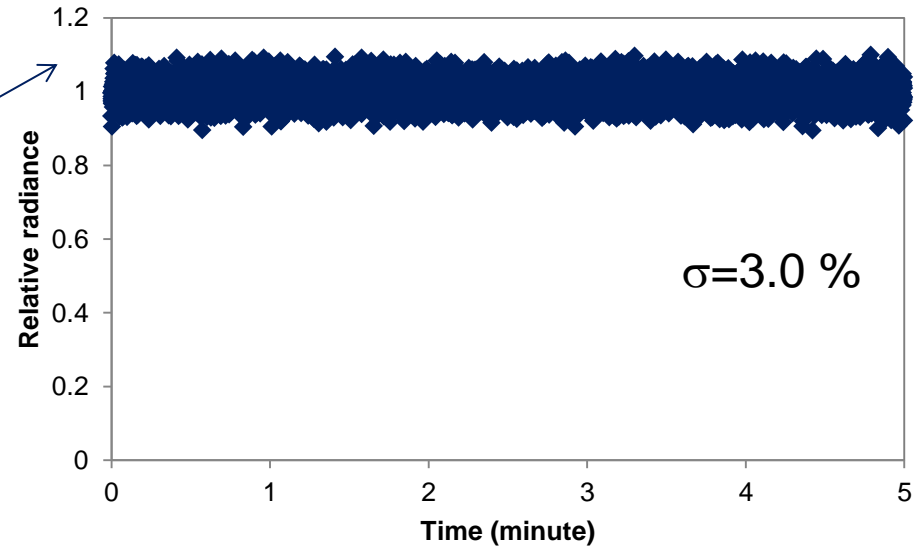
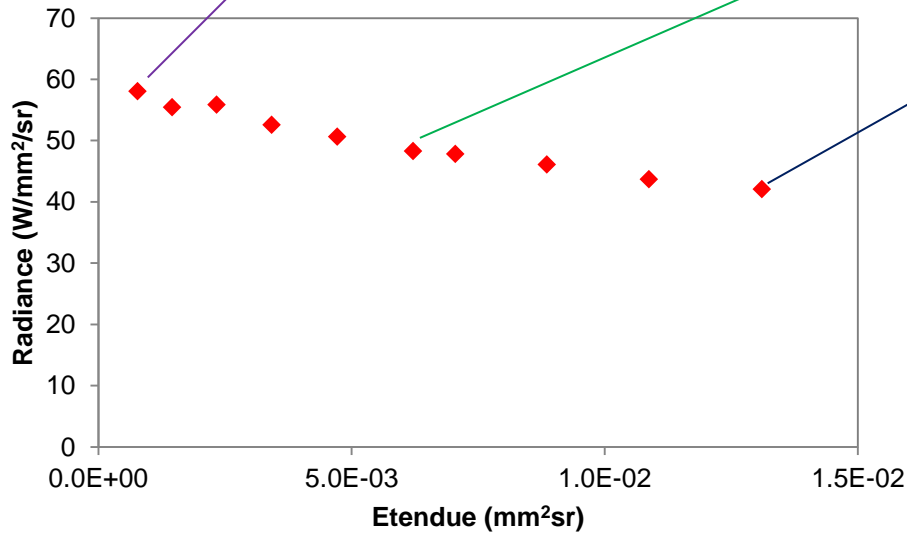
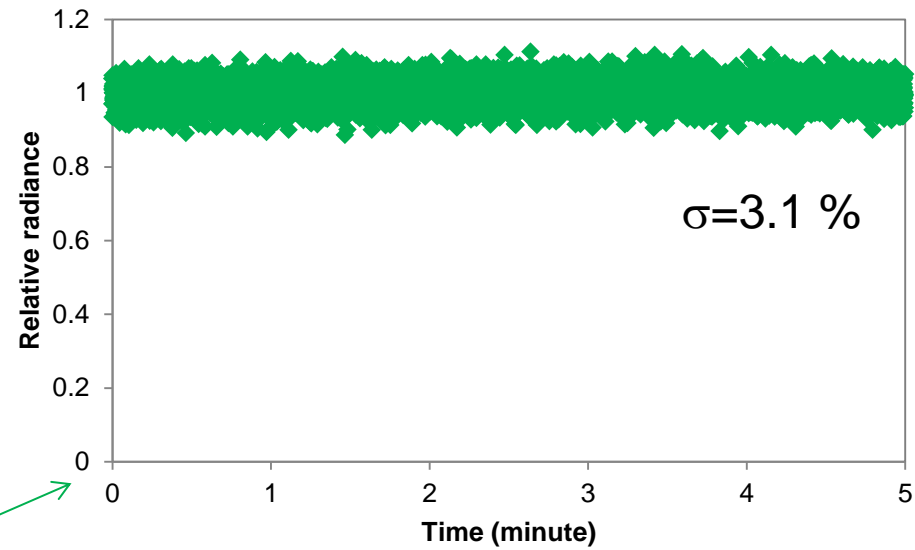
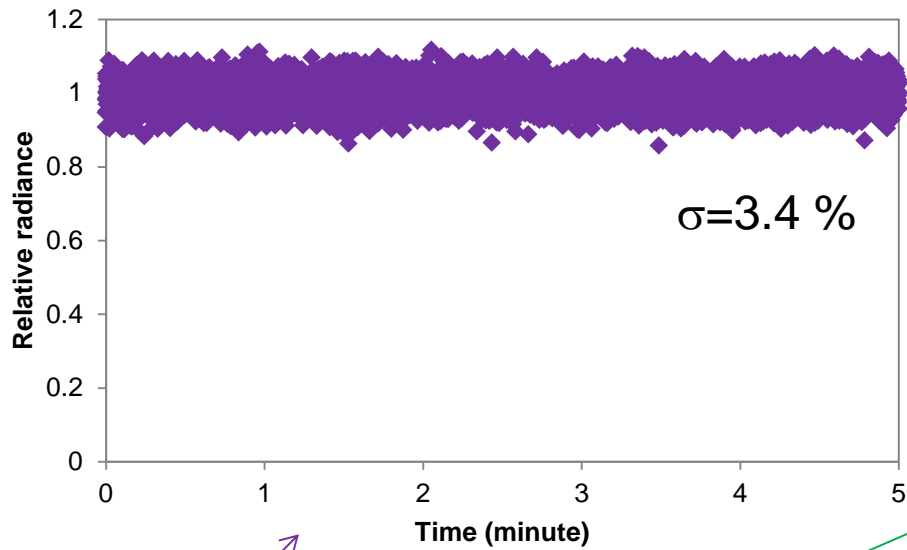


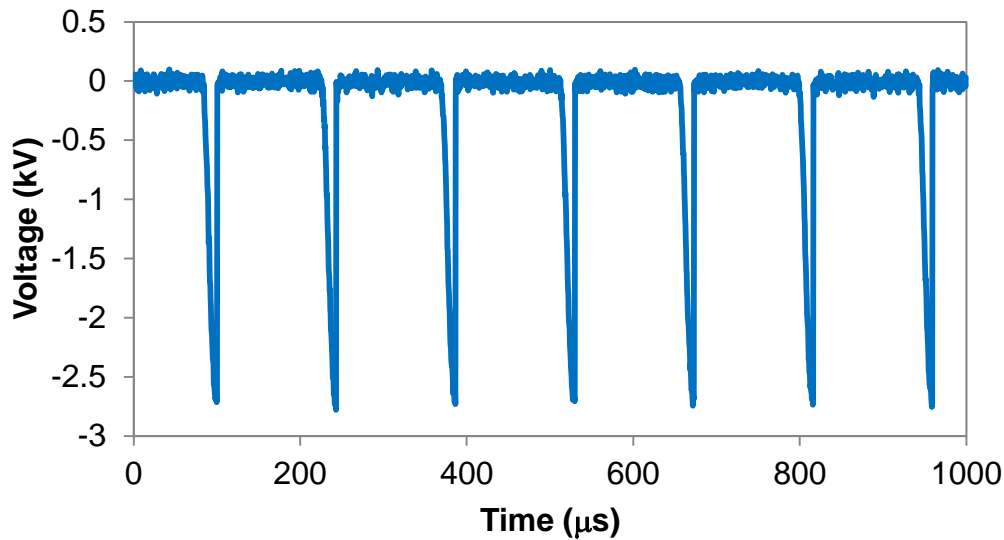
10 kHz, continuous operation

- ❑ Diameter: 200 μm (FWHM)
- ❑ Length: 450 μm (FWHM)

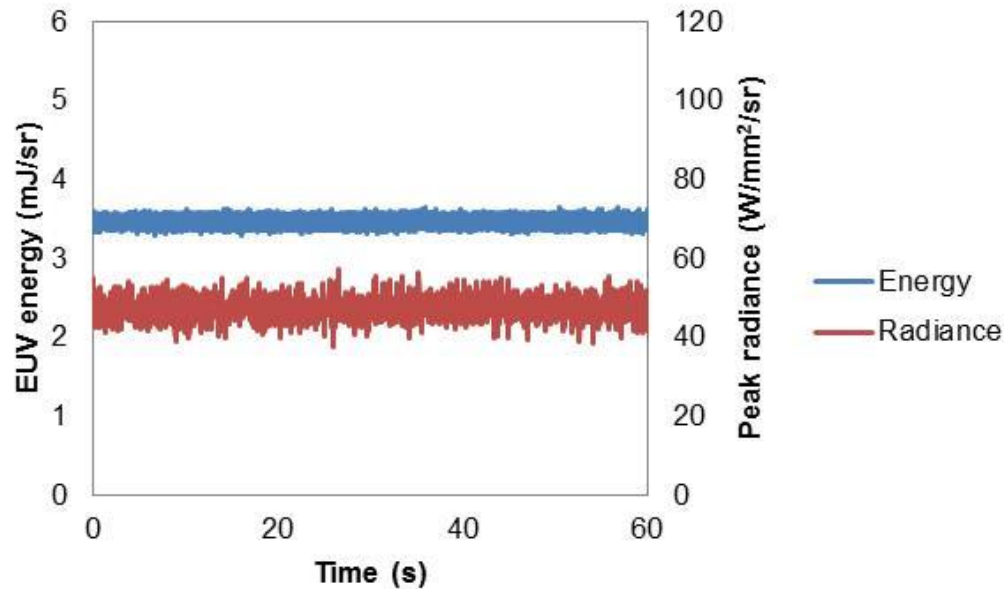
Radiance vs diameter (etendue)

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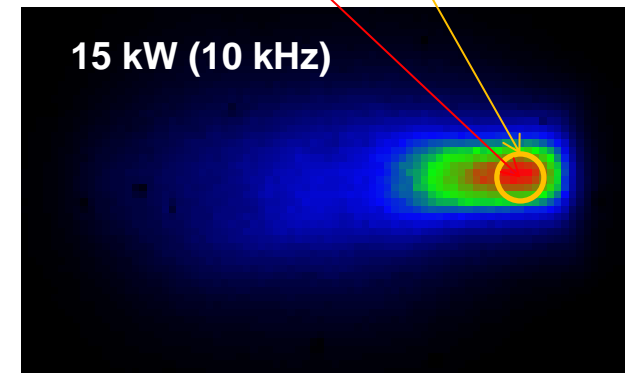
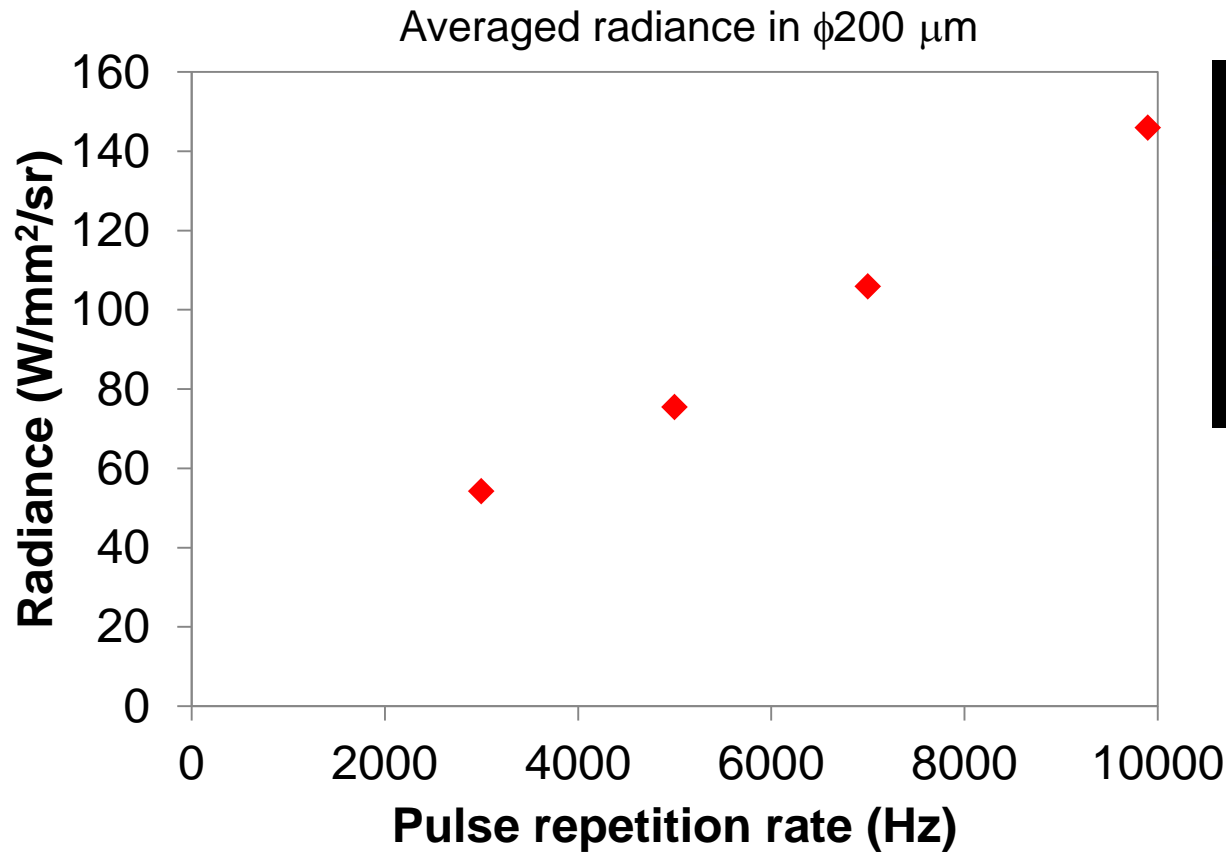


- ✓ Frequency is constant.
- Defined by laser pulse.



- ✓ No missing pulse.
- No misfire.

- Peak radiance: 180 W/mm²/sr
- Area-averaged radiance: 140 W/mm²/sr



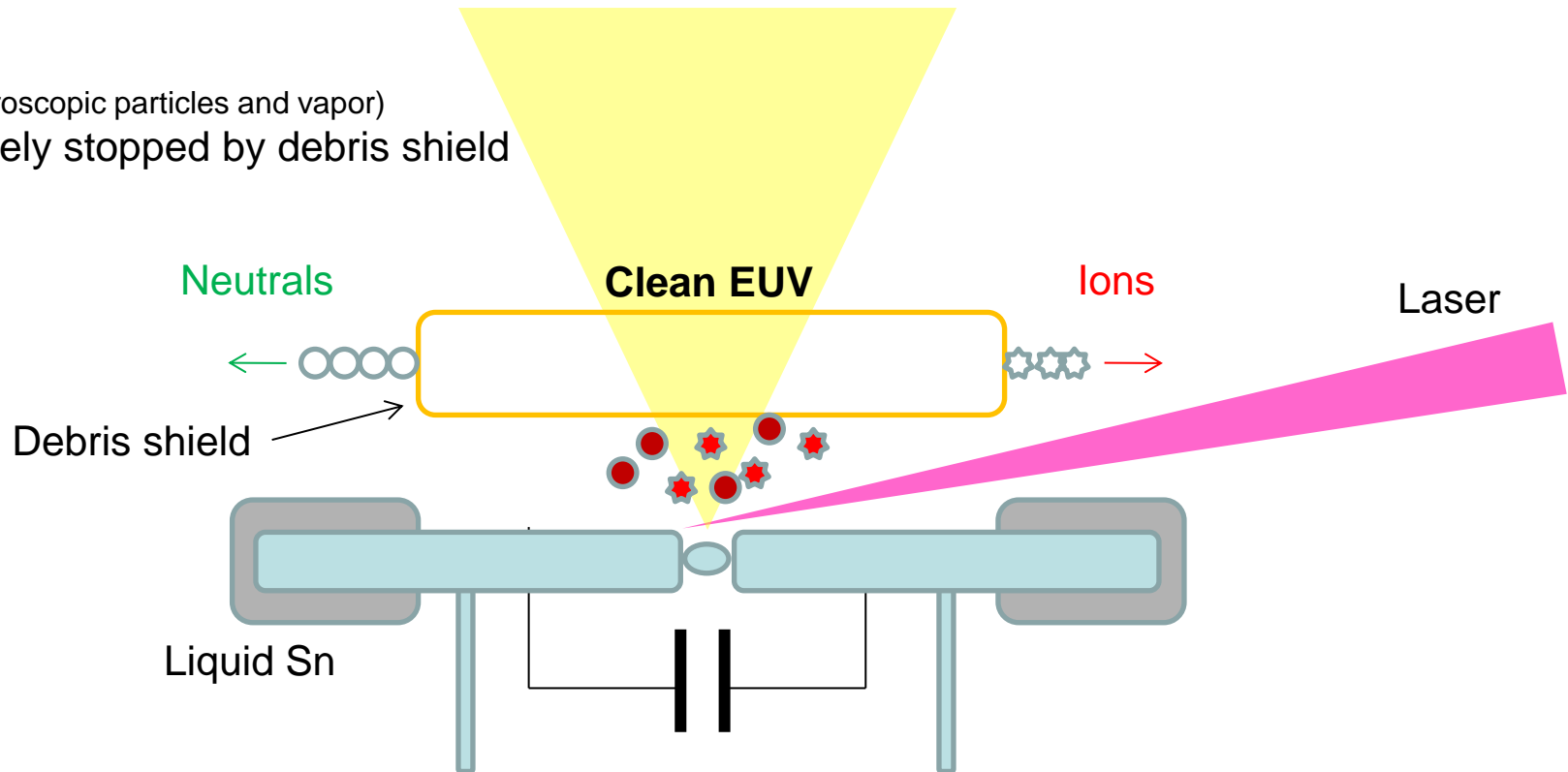
Charged particles (fast ions)

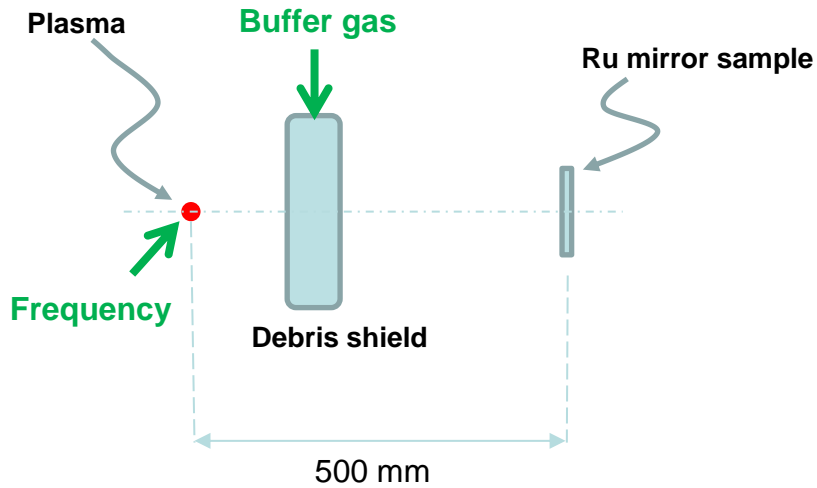
- Mostly stopped by debris shield
- Slow down in debris shield

Neutrals

(Macro/microscopic particles and vapor)

- Completely stopped by debris shield

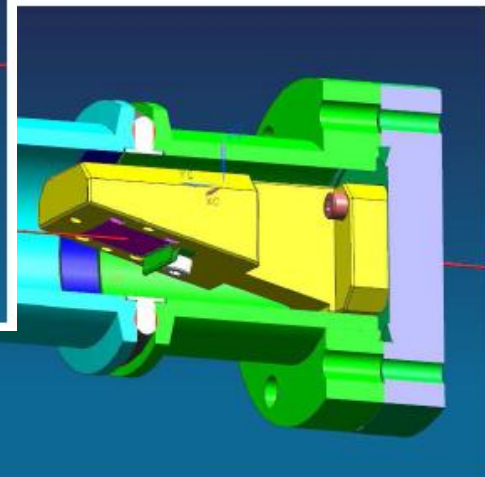
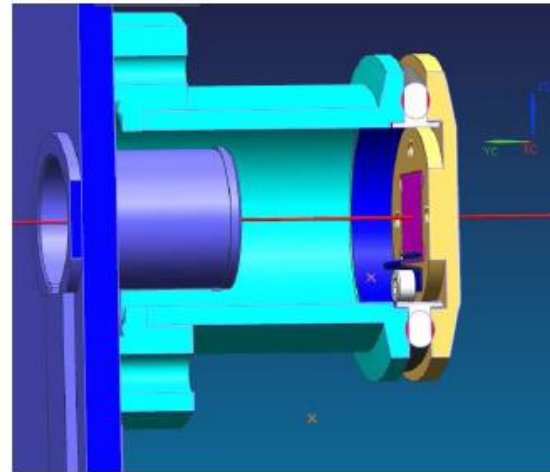




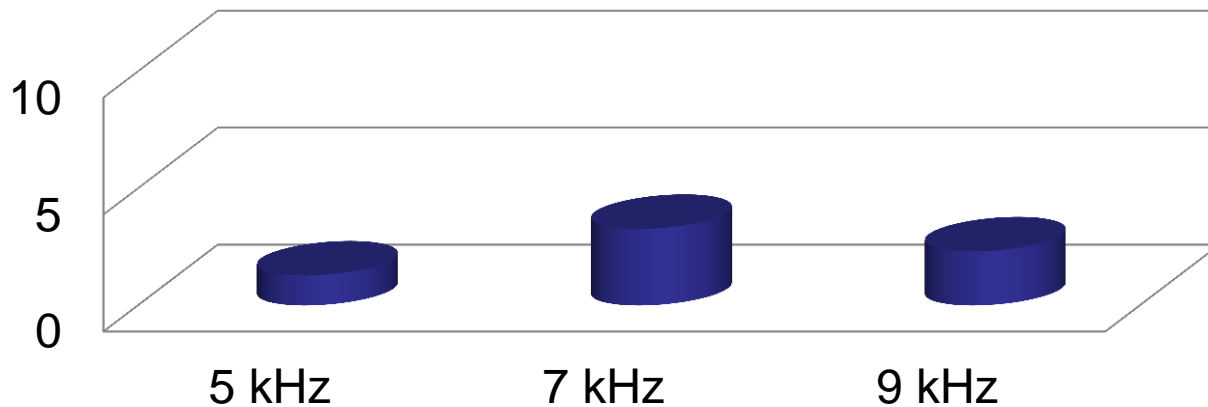
Discharge frequency:
Buffer gas:
Sample:
Source-sample distance:
Incidence angle:
Analysis:

5, 7 and 9 kHz
Variable
8-nm-thick Ru on Si
500 mm
90°, 15°
XRF

After 100~500M pulse

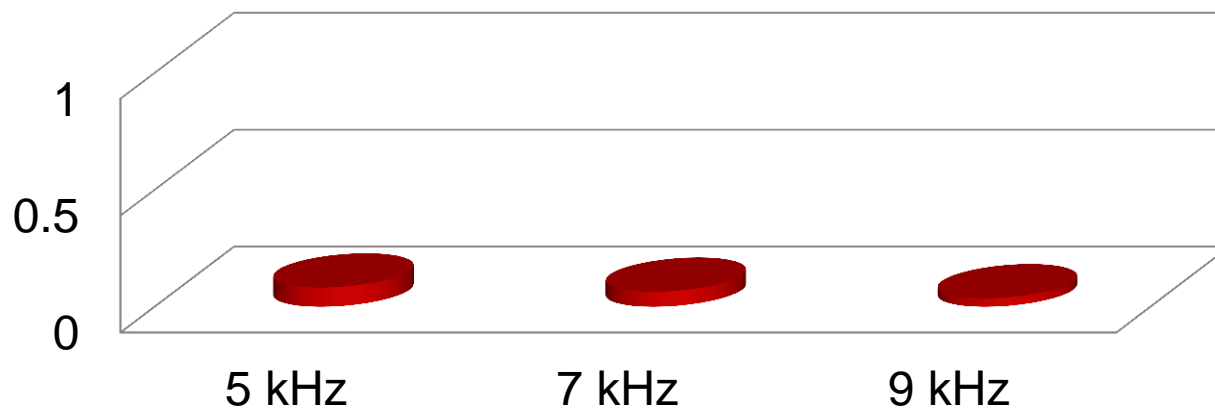


Ru sputter rate (nm/Bpulse)

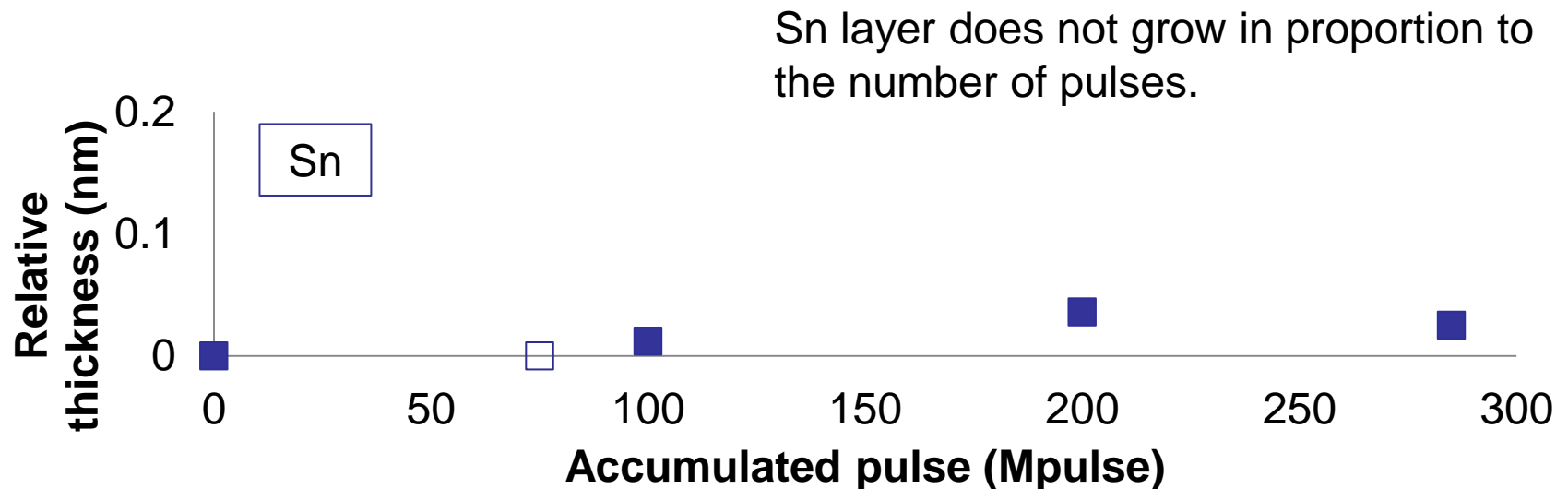
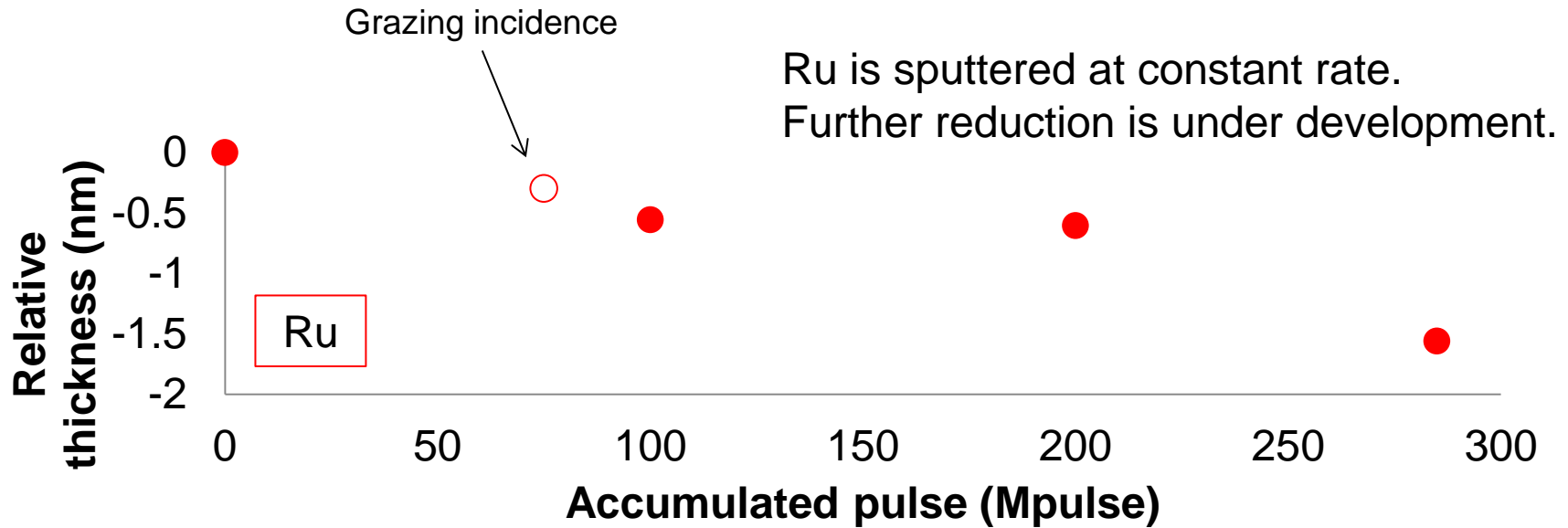


- There is erosion due to ions passing through the debris shield.
- There is a weak relationship between sputter rate and frequency.

Sn deposition (nm)



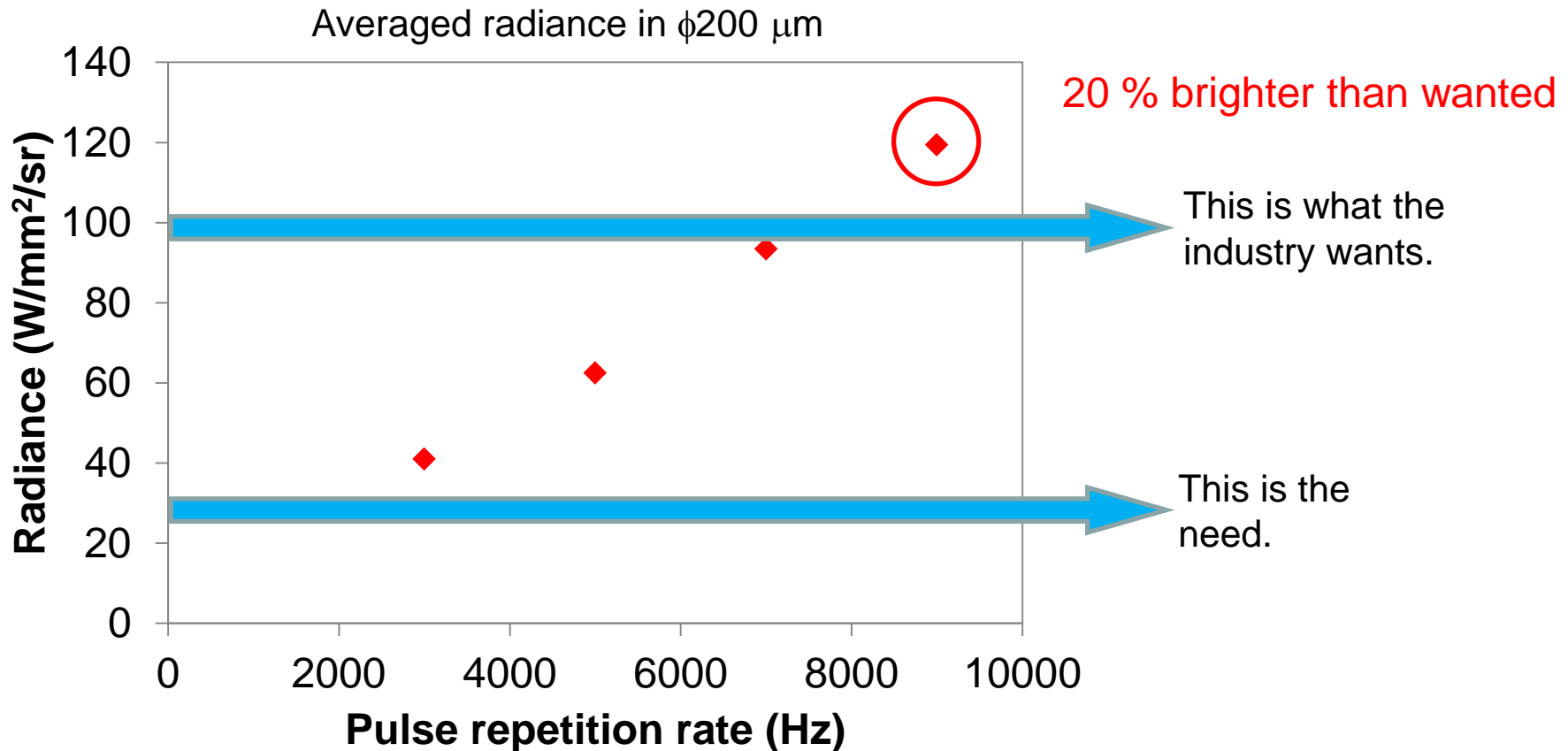
- There is a slight deposition of Sn.
- However, according to the experiments done so far, it does not grow and stops around at <0.1 nm.

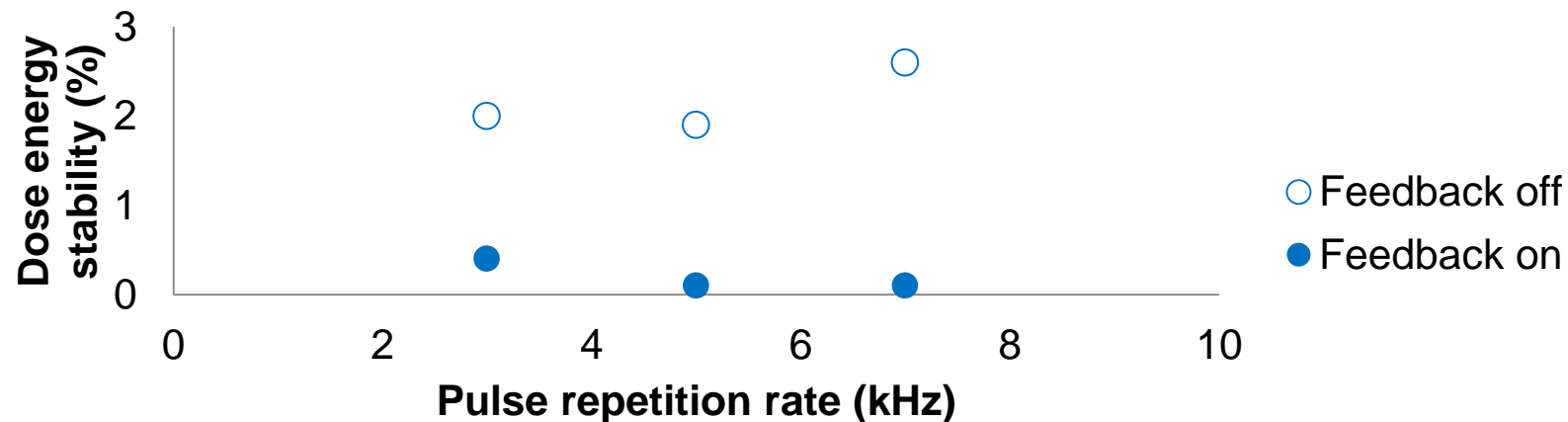
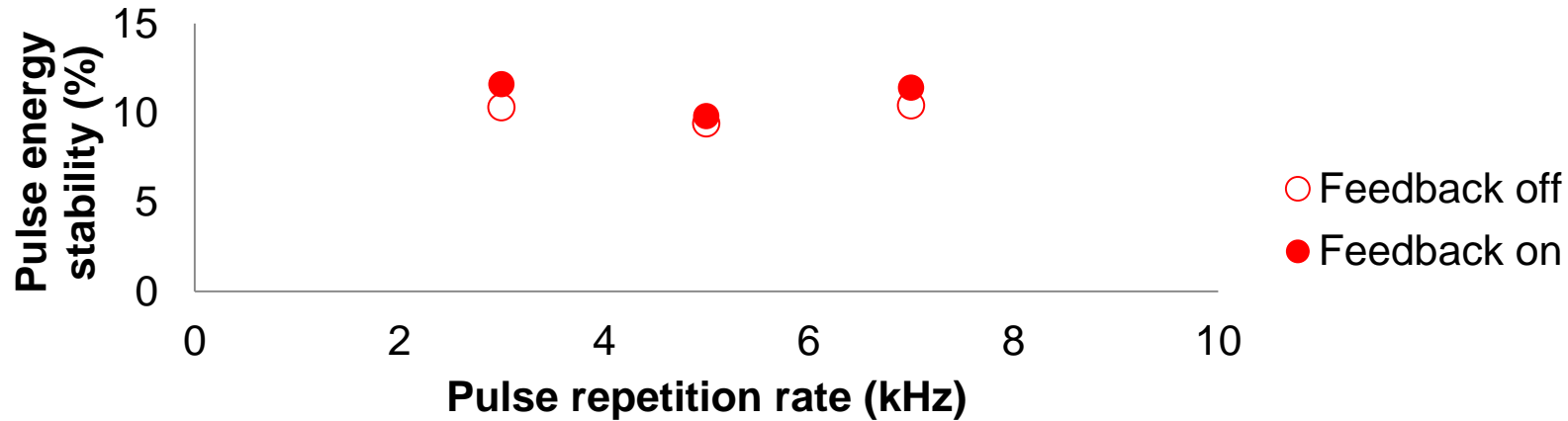


Radiance behind debris shield: 120 W/mm²/sr **USHIO**

Measured **behind debris shield as clean EUV photon**

- Peak radiance: **145 W/mm²/sr**
- Area-averaged radiance: **120 W/mm²/sr**

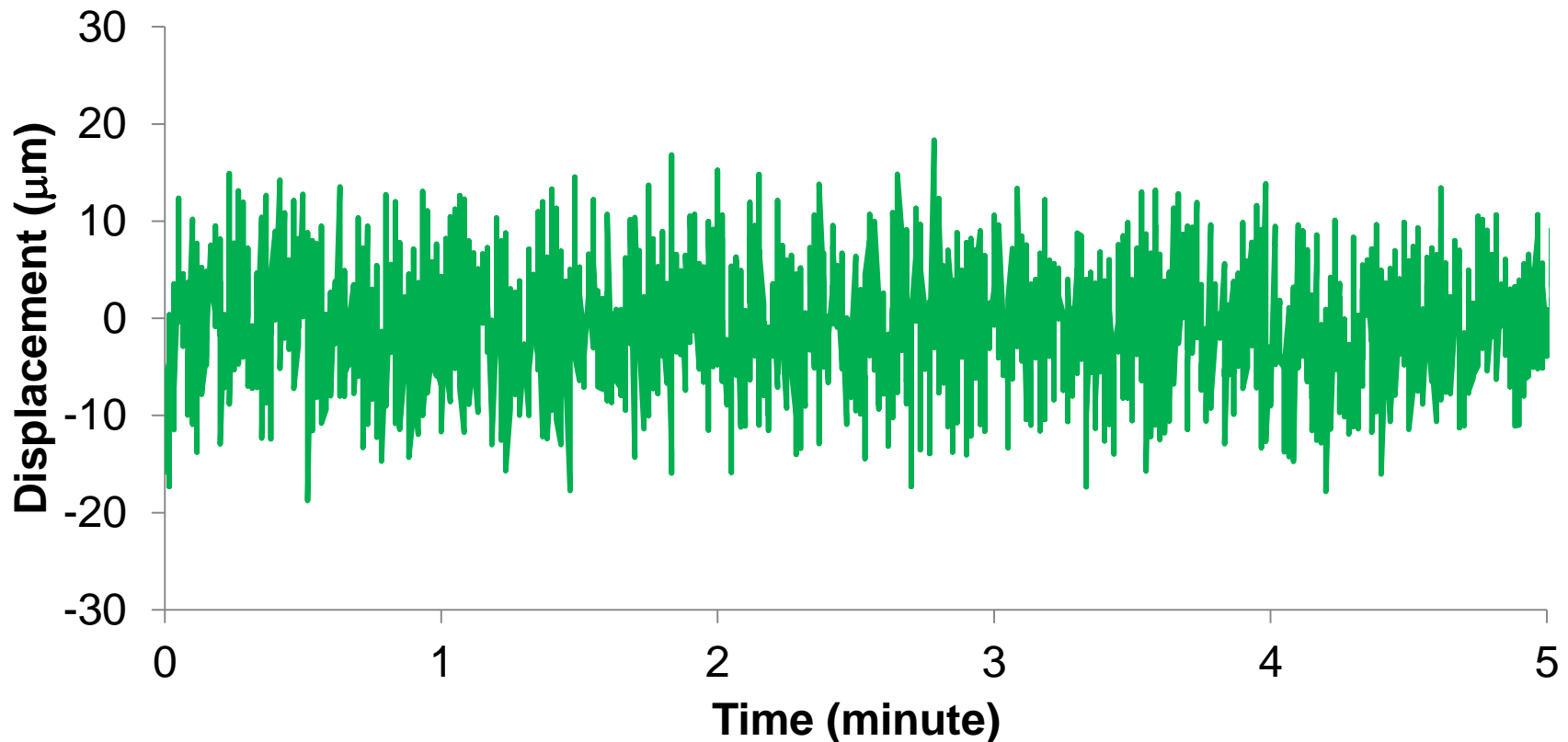




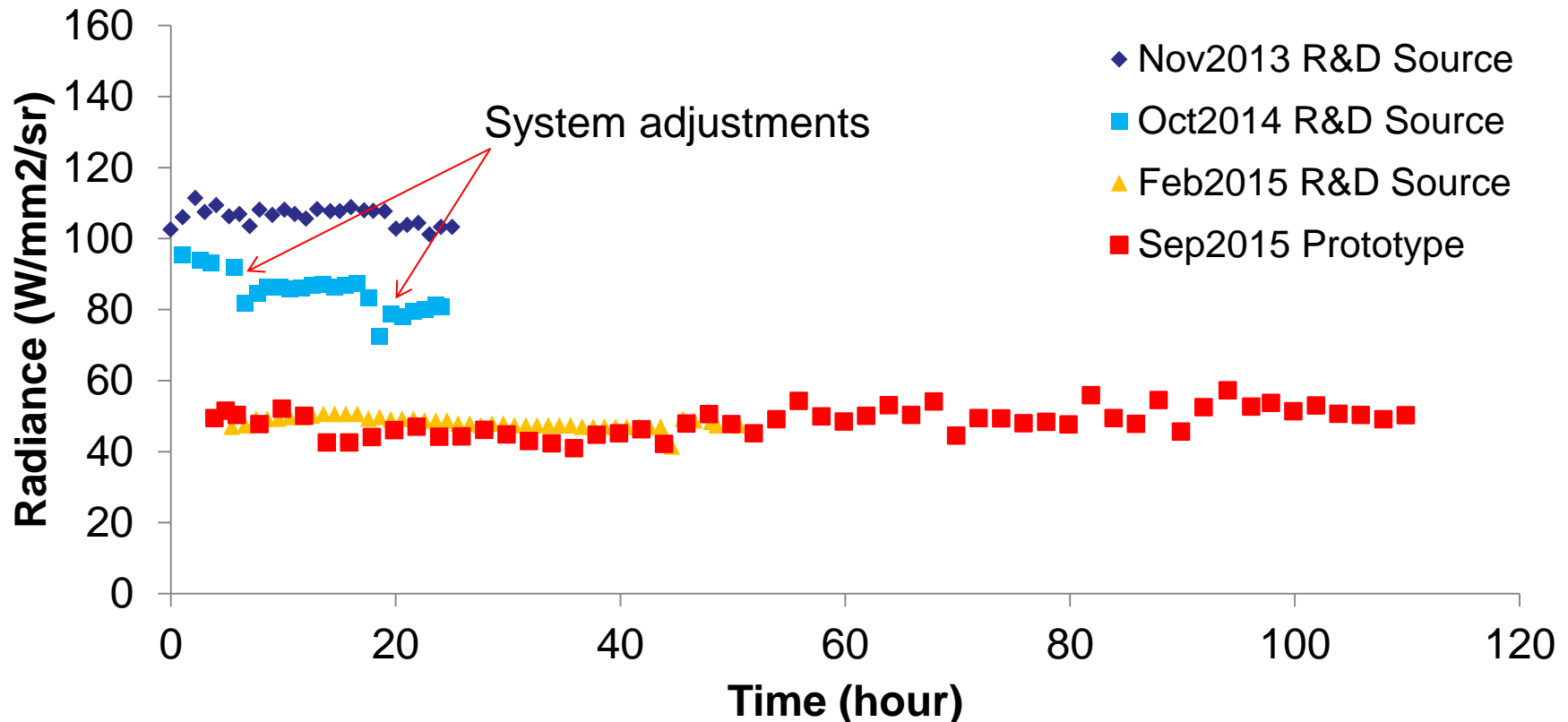
Position stability: $\sim 6\text{ }\mu\text{m}$

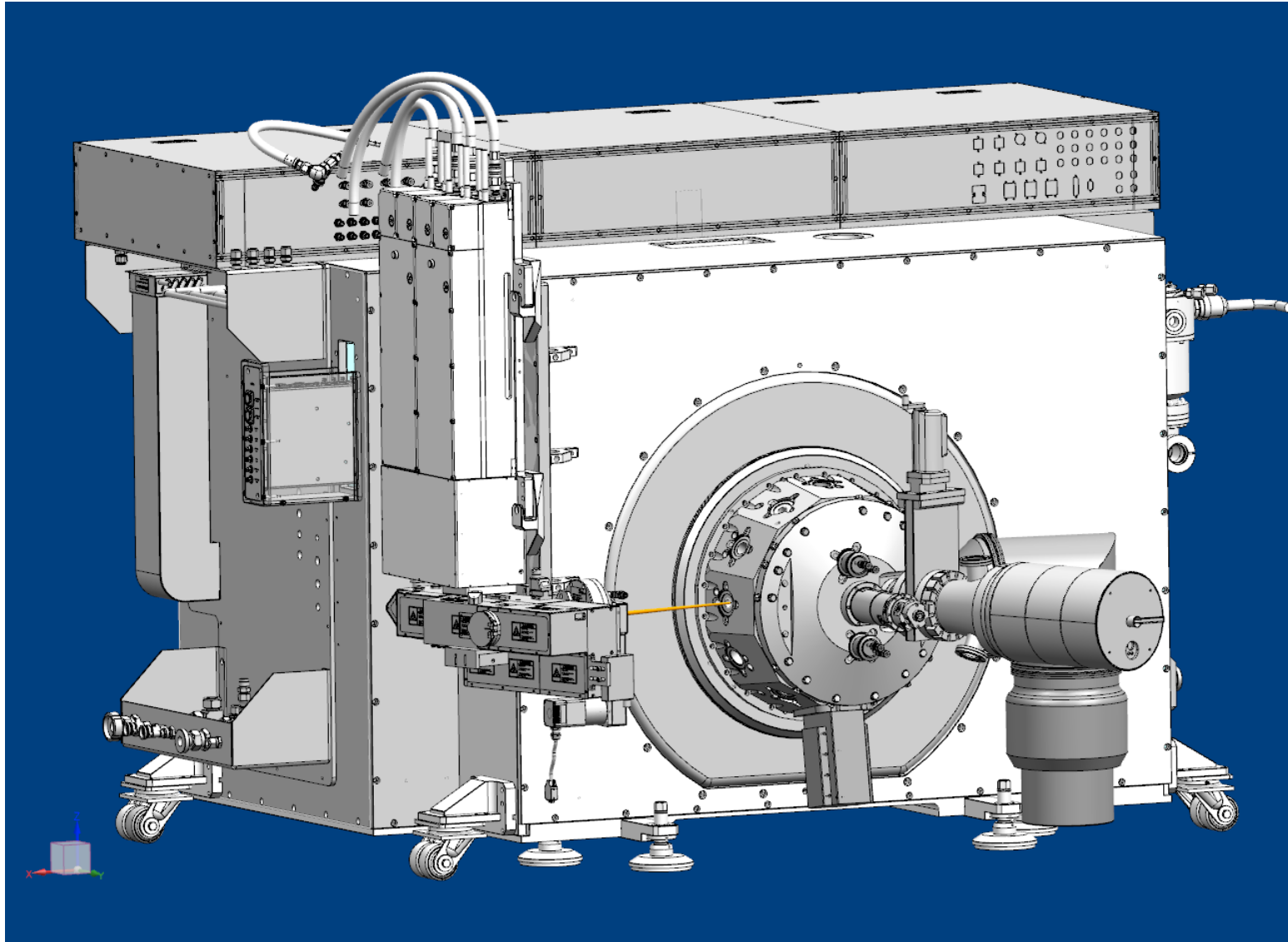
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- ❑ Measured with camera placed on optical axis
 - ❑ Exposure time: 5 ms
- ❑ Standard deviation: $6.0\sim 6.4\text{ }\mu\text{m}$
 - ❑ $<3\%$ of plasma FWHM ($200\text{ }\mu\text{m}$)



- ❑ The prototype machine is dedicated to days-long non-interrupted operation test.
- ❑ Several 5-day operations were carried out.
- ❑ Output radiance will be increased by (1) increasing operation frequency and (2) parameter optimization, and stabilized by (3) applying stabilization control.





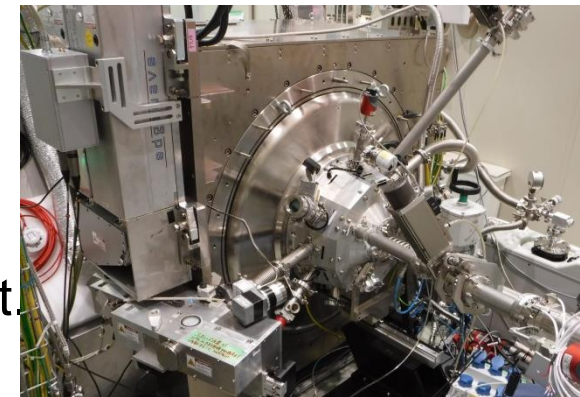
R&D source

- ❑ Energy stability and position stability have been improved.
- ❑ Sample exposure experiments are being performed.
 - ❑ Improved version of the debris shield has been designed and will be tested early 2016.
 - ❑ It has an improved gas distribution leading to better mitigation performance.



Prototype source

- ❑ 5-day non-interrupted operations have been carried out several times.
 - ❑ Successful 5-day-long non-stop operations.
 - ❑ Aiming at system/module reliability improvement.
 - ❑ Stabilization control will be implemented.



Item	Performance	Remark
Pulse repetition frequency	up to 10 kHz	variable
Duty cycle	100 %	
Input power	up to 15 kW	variable
In-band EUV power	up to 300 W/2 π sr	at plasma
Radiance	120 W/mm²/sr* * value measured behind debris shield	9 kHz 200- μ m area averaged
Plasma size	200 \times 450 μ m	FWHM typical value
Energy stability	Pulse: ~10 % Dose: 0.1**~3 % ** with feedback control	
Radiance stability	5.8 %*** ***from 1.5-ms-exposure observation	10 kHz
Position stability	6~10 μ m	